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IMPACT OF VARIOUS FACTORS UPON PAVEMENT CONDITION AND  
MAINTENANCE EXPENDITURES OF SOUTH DAKOTA PRIMARY ARTERIAL ROADS

by

MARK HANSON

A thesis submitted  
in partial fulfillment of the requirements for the  
degree Master of Science

South Dakota State University  
1981

IMPACT OF VARIOUS FACTORS UPON PAVEMENT CONDITION AND  
MAINTENANCE EXPENDITURES OF SOUTH DAKOTA PRIMARY ARTERIAL ROADS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

✓ Charles E. Lamberton      Date  
Thesis Advisor

✓ John E. Thompson      Date  
Head, Economics Dept.

## ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Charles Lamberton, for his guidance through the course of my graduate study. Special thanks must go to Wayne Ellingson for his invaluable help in guiding me through the mysteries of statistical analysis and computer operations. Thanks also to Dr. Ardelle Lundeen for her helpful comments on the manuscript and to Nancy Hurtig for the typing of the thesis. Also, I must mention the South Dakota Department of Transportation for provision of the data.

I would like to express my gratitude to my friends Kevin Anderson, John Kirk, and Steve Venhuizen who allowed me to stay with them while completing this thesis. And, finally, to my parents, Loren and Carleton, for their moral and financial support through my college career.

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## CHAPTER ONE

### INTRODUCTION

#### Problem Statement

South Dakota, predominantly an agricultural state, requires a dependable transportation system to carry its bulk agricultural products from the farm or ranch to the market or processor. Bulk products, a sparse population scattered over a large area, and long distances to the marketplace have led to high transportation costs. Since transportation costs are high relative to the value of agricultural products, these costs have a marked impact upon personal income in the state.

Topography, economics, and accidents of history have played roles in the development of the current system and the problems that plague it. The freight transportation system in the United States consists of three primary modes; barge, rail, and truck. Barges are denied to the state because of a lack of navigable waters. Rail transportation's future has been a concern to both the state and nation for many years. Now highway transportation faces increasing problems.

Rail transportation suffers from a branchline structure that evolved when the railroads had only intramodal competition rather than the intermodal competition that the trucking industry now provides. The branchline structure developed in response to a demand for rail services as the state was being settled. But, at the time of the initial surge in rail building in the state most of the western part of the state was Indian reservation on which rail building was prohibited. This, in addition to the geographic barriers of the Black Hills and Badlands,

fostered the development of a rail system that was composed of branchlines with no transcontinental lines. Thus the system was mostly dependent upon traffic generated within the state. (5, p. 1) As the trucking industry developed, it began to siphon off part of the traffic upon which the railroads had a monopoly. This deteriorated the financial position of some of the branchline railroads, which eventually led to their abandonment.

In the years 1965-1980, 59 branchline railroads with a combined mileage of 2,299.33 were abandoned. The heaviest wave of abandonments occurred in the years 1978-1980 with 33 branchlines with combined mileage of 1,592.5 being abandoned. (2, p. 3)

As rail lines are abandoned, the traffic previously carried on them is shifted to the only alternative, the highway system. The traffic either is shipped directly by truck to its ultimate destination or it is shipped to a point where it can be loaded on a train. Either alternative means more traffic upon the highway system.

However, the highway system may be ill-prepared to cope with the increase in traffic levels. A study commissioned by the U.S. Senate estimated that in 1970 it would have required 625 million dollars to alleviate rural road deficiencies in South Dakota. (10, p. 229) Since that time inflationary pressures have pushed construction costs up 190 percent in the period 1970-1980 and the average maintenance costs per mile rose from \$1,000 per mile to \$2,000 per mile in 1978. (2, p. 19)

During the same period revenues generally have not kept up with the increases in costs. State funds available for state roads increased 102

percent from 1970 to 1980, federal funds available for state roads increased 22 percent in that period, and the increase of the two combined was 103 percent. (2, p. 22)

The principal source of revenues used to construct and maintain the highway system is the motor fuel tax. Revenues from this source increased from \$23.3 million in 1970 to \$42.5 million dollars in 1980. (12 p. 20) The second major source of funding is the motor vehicle registration fee. The revenue from this source increased from 8.5 million in 1970 to \$14.5 million in 1980, a 59 percent increase. (2, p. 21)

The major problem with depending upon these sources of revenues is that they are not based upon the costs of maintaining and constructing the highway system. Rather, the fees are set through the political process. With the economy burdened by stagflation, legislators are reluctant to pass measures that would raise the revenues to the levels of costs. In addition, outside factors play an important role in determining the amount of revenue raised by the fuel tax and the vehicle registration fee.

The increasing price of motor fuel and worries over its continued availability have led to a decrease in the usage. From 1978 to 1980, the consumption of gasoline in South Dakota fell from 525.9 million gallons to an estimated 400 million gallons. (2, p. 21) If the current trend toward more fuel efficient vehicles continues and current economic woes persist, it seems likely that consumption of taxed gasoline will continue to decline. Thus the ability of the tax to raise

revenues adequate to keep pace with increases in maintenance and construction costs, even with increases in the amount of the tax per gallon of fuel, does not seem promising.

The motor vehicle registration fee is not directly impacted by the level of fuel prices, but the factors of political and economic constraints do affect the amount of revenue raised by this source. Legislators do not increase the fee along with the increase in costs. Poor economic conditions, high interest rates, and drought conditions have had an adverse impact on new car sales thus affecting the revenue raised by initial registration fees.

As increases in revenues fall short of the increases in cost it becomes increasingly important to make effective use of the available funds. The approach being adopted now is to concentrate relatively more effort on maintenance than construction. For example, in 1982 expenditures on maintenance and reconstruction are expected to be \$61.7 million as opposed to \$36.7 million in 1980. Construction expenditures, however, are expected to decline to \$77.8 million in 1982 from \$91.3 million in 1980. (2, p. 20) This is not a trend exclusive to South Dakota. For example, capital expenditures in the United States for rural roads fell from \$6,239 million in 1970 to \$3,445 million in 1978 (prices in constant 1967 dollars). During the same period maintenance expenditures remained relatively constant declining to \$2,642 million from \$2,700 (1967 dollars). (8, p. 5)

However, the choice between spending funds on maintenance or construction is a matter of time preference. Many of the maintenance

expenditures are merely a postponement of construction expenditures. In addition, the highways most in need of construction expenditures may be located in areas where the railroad abandonments have the most impact. That these roads may not be able to accommodate the increased truck traffic that may result from the diversion of traffic from railway to highway. (5, p. 2)

Given these problems of increasing levels of traffic on the highways, lessened construction activity and increasing age of the existing network, and a chronic shortfall of revenues to costs there exists a need for information about the highway network in the state which will help to allocate the increasingly scarce resources in the most efficient manner possible. The starting point is to find the determinants of the costs of providing various levels of highway service, quantity and quality, and the functional relationships between the determinants.

### Objectives and Justification

The objectives of this study are as follows:

- (1) To determine what factors have significant impacts upon the level of pavement condition of South Dakota primary arterial roads and to make estimates as to the degree of these impacts.
- (2) To determine what factors have significant impacts upon the level of surface maintenance expenditures of South Dakota primary arterial roads and to make estimates as to the degree of these impacts.

As the process of railroad abandonment occurs there will be more traffic diverted to the state's primary arterial system which is the work horse of the state's highway network. Knowledge of what factors impact levels of pavement condition and maintenance expenditures and estimates of the degree of such impacts could be used as a tool in forecasting the possible consequences of various policy decisions upon the state's highway network. By knowing the possible consequences beforehand, the planning process will be facilitated and better planning decisions can be made.

## CHAPTER TWO

### PROCEDURE

#### Data Description

The data used in the study were obtained from the South Dakota Department of Transportation in a file called the South Dakota Highway Planning Inventory. This inventory covers the bulk of the roads in South Dakota. For purposes of this study, only Rural Principal Arterial Roads have been examined.

Rural Principal Arterial Roads are defined as follows:

"An integrated network made up of the interstate system and major state highways generally serving statewide and interstate travel. This classification is subdivided into the Interstate System and the Other Principal Arterials. Examples of the Other Principal Arterials are U.S. 81 from Watertown south, S.D. 37 from Huron south to Tyndall, U.S. 16 from Lead north, U.S. 14 entire length, and U.S. 12 entire length. The Interstate System is I-29, I-90, and I-190." (6, VII-D-1)

The Rural Principal Arterial Roads in the state are described in the data file by road segments of varying lengths which are described and catalogued into broad categories encompassing geometrics, traffic, structure, deficiency analysis, improvement descriptions, and expenditures. Of these features several have been chosen to be examined in this study based on review of previous research efforts on factors that impact pavement costs and conditions.

Pavement condition is measured by an index called the Present Serviceability Rating (PSR). The Present Serviceability Rating is a number between 0 and 5; 4 is considered good, 3 average, and 2 poor. (4, p. 4)



Although a complex formula exists to determine the PSR of a road (using such components as length of transverse cracking, depth of wheel ruts, etc.) (8, p. 25) the South Dakota Department of Transportation uses a more practical and less complex method of determining the PSR. Experienced highway men are sent out in an automobile to observe the pavement and to assess a rating. In addition, a device called a roughometer is attached to the automobile and measures the pavement roughness. The officials and the roughometer's ratings are combined and a PSR is determined. (7, App. B) The measure of maintenance expenditure used in this study is the annual average roadway surface maintenance expenditure.

It is measured in one hundred dollar units. These cost figures are averaged over the previous two years. A fine line exists between construction and maintenance. Basically, if a project does not include regrading the base course, it can be defined as maintenance. This includes activities such as light overlays, sealing cracks, and filling potholes. Roadway Surface Maintenance does not include activities such as snow removal, mowing, and litter pick-up. (7, App. B)

Variables examined to determine whether they have an impact upon pavement costs and condition are the average daily truck count, the time since resurfacing, the pavement thickness, whether or not the road shoulder is paved, the average annual traffic growth, and the highway district in which the road segment is located.

The first factor is the average daily truck count. This is a measure of the number of trucks and other heavy vehicles that pass over

a particular segment of highway during the course of a day. The average daily truck count variable as a proxy for the actual variable, equivalent axle loadings, which should be used in a study of factors impacting pavement condition.

The equivalent axle load, (EAL), is a measure of the force applied to the pavement. The standard equivalent axle is the amount of force exerted by a single axle loaded at 18000 pounds. For example, an axle loaded at 8000 pounds exerts .0002 EAL's, an axle loaded at 18000 pounds exerts 1 EAL, and an axle loaded at 24000 pounds exerts 3 EAL's. Since the force exerted by an automobile is miniscule compared to a truck, only truck traffic was used as a proxy for the amount of EAL's on the pavement. (4, p. 6)

The average daily truck count (TC) was estimated by multiplying two items on the data file; the average daily traffic count and the percentage of truck traffic. The truck percentage figure includes large commercial vehicles.

The variable, time since resurfacing (TS), is a measure of time which has passed since the road was resurfaced or, if never resurfaced, the time since the road was originally surfaced. The variable is measured in years, and 1979 was used as the base year from which the age of the pavement is determined. Time since resurfacing served as a proxy variable for the host of environmental factors such as spring thaws and temperature variations that cause a pavement to deteriorate over time. (8, p. 17)

The variable, pavement thickness, (PT) was used because the ability of a pavement to tolerate the stresses to which it is subjected will depend in part on how thick it is. (8, p. 30) The pavement thickness is measured in inches. This variable only measures the top layer of the road, the pavement. It does not deal with the subbase.

Paving of the road shoulder (PS) was included as a variable because it has been found that such paving has a beneficial impact upon pavement condition, by preventing moisture from getting under the pavement surface. (1, p. 72) The paving of the road shoulder variable was treated as a dummy variable. A value of zero was assigned to a highway segment that did not have a paved shoulder and a value of one was assigned to a highway segment that did have a paved shoulder.

The average annual traffic growth (AG) variable was used to determine the impact of projected growth in traffic levels upon the allocation of maintenance funds. The average annual traffic growth is expressed as the expected percentage change in traffic level per year. Since this projection may influence the planning process, it was included as a possible determinant of maintenance costs but not of pavement condition.

The final variables that were used represented the highway district in which the highway segment was located. Dummy variables were used to accomplish this. If a segment was in a particular highway district, the dummy variable representing that district will assume a value of one. If the segment is not in that district, the variable will assume a value of zero. There are five highway districts in the state.

The highway district variable was included in the study in order to determine if there are particular conditions in that district which may influence levels of pavement condition or maintenance costs such as differences in environmental conditions, differences in maintenance procedures, or perhaps even measurement bias from one district to another.

Finally, the data is divided into two groups according to whether the pavement is flexible or rigid. Rigid pavements are composed of portland concrete applied to the roadbed in the form of slabs. Flexible pavement is composed of bituminous asphalt material and is applied to the roadbed continuously. (1, p. 171) It is necessary to divide the road segments into these two categories because the pavements deteriorate in different fashions. Rigid pavement will come apart at the slab joints and develop lengthwise cracking. Flexible pavements will be subject to wheel ruts in the pavement surface and will crack in a pattern radiating out from a central flaw.

The variables which were selected for use in the study were not a complete set. The most serious omission was a lack of detailed information about environmental conditions affecting the highway pavement. Important environmental factors are the temperature and the amount of moisture. These variables are important because they tend to magnify the impact of other factors such as axle loadings.

In addition to the important environmental variables, there are other variables that could be added such as the width of tire spacing on trucks, tire pressure of trucks, etc. These variables are not readily

available however, and are not as important as the environmental variables.

The set of variables used is not ideally complete. Average daily truck count would be better expressed as equivalent axle loadings. The paving the road shoulder variable would indicate the type of material used to pave the shoulders. Also, pavements would be split into more categories than flexible or rigid. Flexible pavement in particular is composed of a variety of materials.

A major item for which data are not available is the aspect of timing. More highway damage occurs, for example, in the spring or during a hot summer day than in the fall or evening. Damage to the road also increases as the condition of the road worsens. (4, p. 4)

Even with the few variables being examined in this study, some highway segments in the primary arterial system had to be eliminated due to insufficient data. In the final model, there were 266 highway segments with flexible pavements and 162 segments with rigid pavements.

#### Method Description

To investigate the relationships between pavements conditions (PSR) and maintenance costs (MC) of segments of South Dakota's highways and the many possible factors that can impact these variables, a mathematic model was developed. This model can be represented by a system of two equations as follows:

$$PSR = f_1(TC, TS, PT, PS, DST_i, MC)$$

and

$$MC = f_2(TC, TS, PT, PS, DST_i, AG).$$

The first equation suggests that the Present Serviceability Rating (RSR) is possibly effected by the average daily truck count (TC), time since resurfacing (TS), pavement thickness (PT), whether or not the road segment had a paved shoulder (PS), which highway district the road segment was located, and the expenditures for maintenance (MC).

Likewise, the second equation suggests that maintenance expenditures (MC) are functionally related to average daily truck count (TC), times since resurfacing (TS), pavement thickness (PT), presence or absence of a paved shoulder (PS), which highway district the segment is located, and the average annual traffic growth (AG).

It is hypothesized that this mathematical model can be represented as linear equations of the variables, such as

$$PSR = \alpha_0 + \alpha_1 TC + \alpha_2 TS + \alpha_3 PT + \alpha_4 PS + \sum_{i=1}^4 \alpha_{4+i} DST_i + \alpha_9 MC$$

$$\text{and } MC = B_0 + B_1 TC + B_2 TS + B_3 PT + B_4 PS + B_5 AG + \sum_{i=1}^4 B_{5+i} DST_i$$

What is needed to determine the impact that the variables have on PSR and MC is to estimate the values of the unknown coefficient, that is the  $\alpha$ 's and the B's. To obtain these estimates statistical procedures are used.

The first step is to add a random or stochastic error to each of the equations. This error can arise for many reasons. It can exist because the mathematical equations do not hold exactly or are only approximations. The error can arise due to measurement errors in the variables. They can arise because the model as specified omits some of the relevant variables.

After allowing for the possibility of stochastic errors in each of the equations, appropriate statistical procedures can be used to estimate the unknown coefficients of the model. For the second equation of this model, the procedure used is ordinary least square (OLS). This is appropriate because maintenance expenditures (MC) is the only independent or endogenous variable appearing in the equation. The remaining variables in this equation are assumed to be independent or predetermined variables in that they "determine" the value of MC but the value of MC does not "determine" the values of the remaining variables.

For the first equation of this system a more complicated relationship exists. This complication arises because it is reasonable to expect that not only does the variable maintenance expenditures (MC) affect the variable Present Serviceability Rating (PSR) but also the reverse is true. PSR can affect the MC variable. There is a two-way or simultaneous relationship between these two jointly endogenous variables. In this case OLS estimation procedures are no longer appropriate. Instead two stage least squares (TSLS) can be used to estimate the unknown parameters. In TSLS, the regression is first performed upon the variables which determine the interdependent equation, in this case the maintenance costs. Then the expected values of the maintenance costs are substituted into the equation dealing with the PSR rather than the actual maintenance costs values. The use of this method results in consistent estimators but they are biased due to the substitution of the estimated rather than actual estimators. However, the bias becomes smaller as the number of observations is increased.

### Alternative Functional Forms of the Model

To allow for the possibility that the true functional relationships of the variables are not strictly linear, additional non-linear variations of the model can also be specified. In this study, four different specifications of the relationships were estimated. The first model uses the variables in the linear or untransformed state, the second model uses the logarithmic transformations of the independent variables and the dependent untransformed, the third model uses the logarithmic transformations of the dependent variables and uses the independent variables untransformed, and the fourth model uses the logarithmic transformations of all variables.

### Forecasting and Impact Analysis

Using matrix algebra the system of equation of this model can be written as

$$By = GX + U$$

To obtain forecasts for the jointly endogenous variables PSR and MC, the above equations can be multiplied by  $B^{-1}$ , obtaining

$$y = B^{-1}GX + B^{-1}U = \pi X + V$$

where  $\pi = B^{-1}G$  and  $V = B^{-1}U$

This is called the reduced form of the structural model. Its usefulness lies in the fact that each jointly endogenous variable can be expressed as a linear function of only the predetermined variables and a linear combination of the error terms. To obtain forecasted values of the endogenous variables, we need to have an estimate of  $\pi$  and the observed values of  $X$ , the set of predetermined values. This can be represented by



$$\hat{y} = \hat{\pi}X$$

Where  $y$  denotes the predicted or forecast value of  $y$  and  $\hat{\pi}$  denotes the estimated value of  $\pi$ .

Similarly the impacts that changes in any of the values of pre-determined variables have on the jointly endogenous variables can be computed. This can be seen by writing the reduced form model as

$$\begin{bmatrix} \hat{PSR} \\ \hat{MC} \end{bmatrix} = \begin{bmatrix} \hat{\pi}_{01} & \hat{\pi}_{11} & \hat{\pi}_{21} & \cdots & \hat{\pi}_{10, 1} \\ \hat{\pi}_{02} & \hat{\pi}_{12} & \hat{\pi}_{22} & \cdots & \hat{\pi}_{10, 2} \end{bmatrix} \begin{bmatrix} 1 \\ TC \\ TS \\ PT \\ PS \\ \vdots \\ \vdots \\ DST4 \end{bmatrix}$$

In this form, for example  $\hat{\pi}_{11}$  indicates by how much PSR is impacted by a unit change in TC. Likewise  $\hat{\pi}_{12}$  indicates how a unit change in TC effects the value of MC.

### Criteria for Choosing Between Models

In non-experimental situations such as this study, certain results are expected prior to the performance of the statistical tests. In using a regression analysis of data, prior information or theories will give an expectation as to what sign should be attached to the regression coefficient of certain predetermined variables. Thus, in comparing the models it is valid to examine the equations on the basis of how the signs conform to what is expected. Other factors being equal the model with the anticipated results would be preferred.

In this study it developed that there were no differences on signs of regression coefficients between models on the variables that were found to be statistically significant.

Other criteria for comparing different models are the various summary statistics. Summary statistics commonly used are the multiple correlation coefficient, the mean standard error, and the F statistic.

The multiple correlation coefficient is probably the most commonly used summary statistic. It measures the amount of variation in the dependent variables which is caused by the variation in the independent variables. The value of the multiple correlation coefficient,  $R$ , must fall between 0 and 1 since variations in the independent variables can account for none, all, or somewhere between of the variations of the dependent variables. Unfortunately, the computational procedure used to determine the  $R^2$ , when used in an equation estimated by two stage least squares can yield a result with a value less than 0. Therefore  $R^2$  will not be used in this study for comparing the results of equations with more than one endogenous variable in the equation.

Like the multiple correlation coefficient, the mean sum of squares seeks to explain what variation of the dependent variables is explained by variation in the independent variables. The means sum of squares (mss) is computed by summing the squares of the differences of the predicted Y's from the actual Y's, then dividing by the degrees of freedom. The smaller the mean sum of squares, the better the equation explains the variation of the dependent variables. The comparison can only be made between like dependent variables. Thus, in this study valid comparisons using this statistic can be made between model using the dependent variable in linear form and between models using the dependent variable in logarithmic form. Unlike the correlation coefficient, mean sum of squares is compatible with two stage least squares.

The F statistic is a measure of the explanatory power of the equation. It measures how much the variation of the dependent variables differs from the results that would occur if the variation was due strictly to chance. The larger the F statistic, the less of the variation is attributable to chance.

In examining the results of the regression runs of the four models, it was determined that there was not much difference between the models based on the criteria used to select one. Therefore it was decided to use the models with variables in the linear form because of a desire to use the simplest version possible.

## CHAPTER THREE

### EMPIRICAL RESULTS

For purposes of presenting the regression equations the following abbreviations were used for the variables included in the equations.

TC = Average Daily Truck Count

TS = Time Since Resurfacing

PT = Pavement Thickness

PS = Paved Shoulder

MC = Average Annual Surface Maintenance  
Costs Per Mile

AG = Average Annual Traffic Growth

DST1 = Highway District 1

DST2 = Highway District 2

DST3 = Highway District 3

DST4 = Highway District 4

Although there are five highway districts, only the dummy variables for four districts are included in the model.

If dummy variables for all five highway districts were included in the model, unique solutions would not be determined for the regression coefficients. The impact of the fifth district upon the dependent variables shows up in the constant.

The regression results will be reported in the following fashion.

$$PSR = 3.2998 + .0002TC + \dots 2557DST4$$

$$(9.39)^* \quad (1.04) \quad (2.21)^*$$

The first term is the regression intercept. The terms preceding the variable names are the values of the regression coefficients. The terms in the parentheses are the values of the t tests performed upon the regression coefficient. An asterisk (\*) indicates whether the t tests pass the .05 level of significance. In addition, an F test for the entire equation and the mean square errors are presented. The F statistic will be noted by an asterisk if it passes the .05 level of significance.

### Structural Models

#### Rigid Pavement Group

As noted, the model using all the variables in linear functional form was chosen. In this model the interpretation of the regression coefficients is that they measure the change in the dependent variable given a unit change in the independent variable assuming the other variables are held constant.

$$\text{PSR} = 3.2998 + .0002\text{TC} - .0148\text{TS} + .0074\text{PT} + .4539\text{PS} - .0180\text{MC} - .0411\text{DST1}$$

(9.39)\*    (1.04)    (-3.50)\*    (2.24)\*    (3.48)\*    (-2.50)\*    (-.31)

$$+ .0479\text{DST2} - .1454\text{DST3} + .2557\text{DST4}$$

(.42)    (-1.47)    (2.21)\*    F Ratio = 15.34\*    MSS = .1233

$$\text{MC} = 12.9091 + .0053\text{TC} + .1216\text{TS} - .0545\text{PT} - 5.384\text{PS} + .0170\text{AG} - 2.933\text{DST1}$$

(3.29)\*    (1.87)    (2.64)\*    (-1.44)    (-3.83)\*    (1.91)    (1.99)\*

$$- 2.6147\text{DST2} - 3.9286\text{DST3} - 1.1153\text{DST4}$$

(-2.12)\*    (-3.71)\*    (-1.86)    F Ratio = 10.82\*    MSS = 15.2559

#### Flexible Pavement Group

The model using the variables in linear forms was also chosen for the flexible pavement group.

$$\text{PSR} = 4.00 + .0002\text{TC} - .0328\text{TS} + .0198\text{PT} + .1849\text{PS} - .9165\text{MC} + .0227\text{DST1}$$

(31.43)\*    (.87)    (-8.37)\*    (.123)    (2.58)\*    (-3.97)\*    (.21)

$$+ .0892\text{DST2} - .0843\text{DST3} - .1205\text{DST4}$$

(.86)    (-.75)    (-3.97)\*    F Ratio = 20.26\*    MSS = .2745

$$\text{MC} = 6.61 - .0062\text{TC} + .2719\text{TS} - .0099\text{PT} + .3197\text{PS} + .0389\text{AG} - 1.4149\text{DST1}$$

(3.56)\*    (-1.27)    (4.86)\*    (-.41)    (.30)    (2.18)\*    (-.89)

$$+ .0279\text{DST2} + 2.2674\text{DST3} + .3704\text{DST4}$$

(.01)    (1.35)    (.28)    F Ratio = 4.31\*    MSS = 60.786

### Models with Reduced Form Coefficients

#### Rigid Pavements

$$\text{PSR} = 3.0674 + .0001\text{TC} - .0083\text{PT} + .5508\text{PS} - .0003\text{AG} + .0116\text{DST1}$$

$$+ .0949\text{DST2} - .0746\text{DST3} + .2757\text{DST4}$$

$$\text{MC} = 12.9091 + .0053\text{TC} + .1216\text{TS} - .0545\text{PT} - 5.3850\text{PS} + .0170\text{AG}$$

$$- 2.9330\text{DST1} - 2.6147\text{DST2} - 3.9286\text{DST3} - 1.1153\text{DST4}$$

#### Flexible Pavements

$$\text{PSR} = 3.9809 + .0003\text{TC} - .0372\text{TS} - .0199\text{PT} + .1796\text{PS} - .0006\text{AG} + .0460\text{DST1}$$

$$+ .0885\text{DST2} - .1217\text{DST3} - .1266\text{DST4}$$

$$\text{MC} = 6.6100 - .0062\text{TC} + .2719\text{TS} - .0099\text{PT} + .3197\text{PS} + .0389\text{AG} - 1.4149\text{DST1}$$

$$+ .0279\text{DST2} + 2.2674\text{DST3} + .3704\text{DST4}$$

### Interpretations of Regressions

In interpreting the results of the regression analysis the items of most concern were the level of significance of the t tests performed upon the regression coefficients, the signs of the regression coefficients, and the values of the regression coefficients.

Items found to be statistically significant in the equation dealing with rigid pavement PSR were the constant, time since resurfacing, pave-

ment thickness, paving the road shoulder, the level of maintenance costs, and location in highway district four. Items found to be statistically significant in impacting the level of maintenance costs were the constant, time since resurfacing, paving the road shoulder, and location in highway district one, two, and three.

Items found to be statistically significant in the equation dealing with flexible pavement PSR were the constant, time since resurfacing, paving the road shoulder, the level of maintenance costs and location in district four. Items found to be statistically significant in impacting the level of maintenance expenditures were the constant, the time since resurfacing, and the average annual traffic growth.

The sign of the regression coefficient was compared with its expected sign. In evaluating the impact of the signs of the coefficients, only variables which were statistically significant in one of the regression equations are discussed.

It was postulated that an inverse sign would be attached to the common variables in the simultaneous equation model. For example, if a variable had a positive sign in the portion of the regression model dealing with the pavement condition, it was expected that the regression coefficient attached to that variable in the maintenance costs part of the model would have a negative sign because of assumed inverse relationship between the level of maintenance costs and the level of pavement condition.

Since accumulated axle loadings are supposed to have a negative impact upon pavement condition, it was anticipated that the proxy variable

for this (TC) would have a positive impact upon the level of maintenance costs. As the pavement increases in age (TS) the level of the PSR will deteriorate and a negative sign will be attached to the regression coefficient. Therefore, as the pavement ages more maintenance will be required and a positive sign will be attached to the coefficient of the variable in the maintenance cost model. An increase in the thickness of the pavement (PT) is expected to make the pavement stronger and therefore maintain a higher level of condition than a thinner pavement which would result in a positive regression coefficient for the variable and require less maintenance which would result in negative regression coefficients.

The variable included only in the maintenance cost part of the simultaneous regression equation model, average annual traffic growth, was expected to have a positive regression coefficient. It was believed that, in the planning process for maintenance expenditures, more would be allocated to segments of highways anticipated to serve heavier volumes of traffic in the future.

Since the variables designating the number of the highway district in which the highway segment was located were not included in the model to measure one direct impact, no particular sign was expected for the district variables. Seeing if the opposite sign relationship held between the coefficients of the two parts of the model was thought to be illuminating, however.

If the signs developed as expected then the impacts that were assumed in deriving the expectation of the sign are assumed to be in



action. However, if an unexpected or anomalous sign appears, then alternative explanations must be sought to account for the anomaly.

Initially, it was assumed that the maintenance cost variable acting as a jointly endogenous variable in the pavement condition equation would have a positive regression coefficient. It was anticipated that as a highway segment received additional maintenance expenditures, it would suffer less serviceability loss than a pavement which did not. However, in both the models examining the two groups of pavements the regression coefficient for the maintenance cost variable was found to be statistically significant and to have a negative sign.

Alternative explanations can be offered for this result. The simplest is that increased maintenance expenditures lead to lower levels of pavement condition. This hypothesis does not seem very likely, however. The explanation advanced here for this anomalous result is that the negative coefficient attached to the maintenance cost variable reflects the decision to allocate maintenance expenditures to lower quality pavements. Although the positive effect upon pavement condition of maintenance cost might occur, it may be overshadowed by the alternative effect. In addition, the negative sign is more consistent with the assumption of inverse signs between variables in common of the two parts of the model.

In both models the anticipated signs occurred for all the variables found to be statistically significant save for the maintenance cost variable in the pavement condition been above. None of the highway district variables were found to be mutually statistically significant

in the pavement condition and maintenance cost portions of the model and it is therefore not possible to determine if the inverse relationship also exists among those variables.

In the rigid pavement group, location in district four was positively related to the level of maintenance costs. Location in either district one, two, or three had a negative impact upon the level of maintenance costs. None of the highway district variables were found statistically significant in the flexible pavement group.

The major surprise in terms of the significance of variables was the fact that the truck count (TC) variable was not found significant in any of the models. This suggests that use of the proxy variable, truck count, may be inappropriate. Another possibility is that there is not enough variation in the amount of truck traffic on the various highway segments in the state for the variable to show up as statistically significant. Or, total traffic may be so low that the "damage threshold" is not reached. Or, South Dakota highways are too young to show effect.

The third item to examine in the regression results is the actual value of the regression coefficients. It is not correct to evaluate the regression coefficients by comparing their absolute values since the units of each independent variable are different. Rather, it may be more useful to look at differences between the flexible and rigid models. As a general observation it seems that the variables have more impact upon the flexible pavement condition and maintenance cost. This might be interpreted that the deterioration and maintenance expenditure

on a rigid pavement is less in any given year than for a flexible pavement. However, the initial construction expenditure for a rigid pavement is greater.

## CHAPTER FOUR

### RECOMMENDATIONS AND LIMITATIONS

In considering the factors that impact pavement condition and costs on South Dakota primary arterial highways, the problem was so aggregate that only statistical techniques could be used. Given optimal conditions with data that conform to the rigor that regression analysis requires in theory, the results of a statistical operation will still be less satisfactory than actual observation and measurement. An applied situation is subject to more chaos and imperfections.

Some of the limitations of this study have been mentioned earlier. One is the incomplete specification of the variables used, such as using proxy variables as average daily truck count for equivalent axle loadings. Another limitation is the incomplete specification of the regression equation, i.e., not including all the factors which should be included in equations describing the characteristics of pavement condition and maintenance expenditure.

The use of regression analysis itself can lead to problems. All the assumptions that classical regression analysis requires; i.e., no multicollinearity, no heteroscedasticity, no autocorrelation, etc., are seldom met in an applied situation.

#### Uses of Study

This study is intended to serve as a guide to those factors which impact pavement condition and maintenance cost. More detailed work is necessary to make accurate judgments upon the full extent of these im-

pacts, but that is the province of the engineering profession. The information in this study is intended to act as a somewhat crude guide to facilitate the more efficient allocation of resources to help make trade-off decisions, a process which many have defined as economics.

An example of how the results of this study can be used is illustrated in a project examining the economic feasibility of a rail branchline from Napa, SD to Platte, SD. In a section describing alternative results if the branchline was abandoned, regression coefficients which were obtained in some of the preliminary work of this study were used to determine the impact on highways in the region affected by the rail abandonment. The method used was to determine the amount of traffic carried by the rail line and to assume that it would all divert to truck traffic and would be carried by the highway system in the region. The additional amount of truck traffic was then multiplied by the regression coefficient for the truck count (TC) to obtain an estimate of the decline in serviceability or the increase in maintenance costs as a result of the increased truck traffic on the highways due to the rail line abandonment. (3, p. 1.14)

The estimates of the factors that impact pavement condition and maintenance cost can be used in a benefit-cost model or optimization model if more detailed information on other factors which affect cost level or the benefits to the users of the transportation system in the state were to be incorporated into the models. Such information as cost of traffic on other modes of transportation, user costs on modes of transport, demand for transportation services, etc. would be necessary

to use models of this sort. Such models could be used to determine how a given change in the state's transportation system will act upon the primary arterial highways or conversely, how a given change in the state's primary arterial highway system will affect the state's transportation system.

### Conclusion

Due to the continued abandonment of railroad trackage in South Dakota, the primary arterial highway system will be subject to increasing strains upon its capacity. This shift in traffic will also mean a shift of responsibility for maintaining the structure necessary to accommodate the traffic from the private sector to the public. Thus in times of severe constraints, planning and forecasting the consequences of these shifts becomes increasingly important.

The objective of this study was to point to some of the factors and the degree to which they affect the pavement condition and maintenance cost. The factors found to be important were pavement thickness and paving the road shoulder for both condition and maintenance cost variables. Maintenance cost had an impact upon pavement condition. The traffic growth had an impact upon maintenance costs. The truck count did not show an impact upon either pavement condition or maintenance costs. Various highway district dummy variables were found to be significant but to pinpoint why would take further study.

As previously mentioned, for the results of this study to be very useful, it is necessary to have much more data on other factors. This should be done as the realization dawns that the emphasis of the state

should be on developing a transportation system rather than transportation systems. Developing an efficient system is particularly important in South Dakota, a relatively poor state, where the cost of maintaining the transportation system is relatively high per capita. As revenue problems and costs increase, the need for planning also increases. It is hoped that the results of this study can be used in such an effort.

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## APPENDIX

## APPENDIX

The following tables contain the regression coefficients of all the final regression models that were run. The tables contain the value of the regression coefficient, the statistics in parenthesis below the regression coefficient, and an asterisk to indicate whether the t tests show the variable was at or beyond the .05 level of significance.

## FLEXIBLE PAVEMENT PSR

	$Y=X_i$	$Y=\ln X_i$	$\ln Y=X_i$	$\ln Y=\ln X_i$
BO	4.000 (31.43)*	3.1973 (6.96)*	1.3807 (35.45)*	1.1189 (7.94)*
TC	.0002 (.87)	.0930 (1.25)	.0001 (1.32)	.0396 (1.75)
TS	-.0328 (-8.37)*	-.1769 (-4.56)*	-.0101 (-8.48)*	-.0540 (-4.54)
PT	.0198 (1.23)	.1718 (2.01)	.003 (.65)	.0381 (1.46)
PS	.1849 (2.58)*	.2545 (3.31)*	.0541 (3.47)*	.0757 (3.21)*
MC	-.0165 (3.97)*	-.2160 (-5.20)*	-.0043 (-3.37)*	-.0590 (-4.63)*
DST1	.0227 (.21)	-.0116 (-.10)	.0173 (.53)	.0051 (.14)
DST2	.0892 (.86)	.1194 (1.05)	.0295 (.94)	.0384 (1.10)
DST3	-.0843 (-.75)	-.0549 (-.44)	-.0197 (-.57)	-.0124 (-.33)
DST4	-.1205 (-1.139)	-.1032 (-1.09)	-.0387 (-1.46)	-.0360 (-1.24)
F Ratio	20.26*	12.61*	19.22*	11.52*
MSE	.2745	.3257	.0257	.0306

## FLEXIBLE PAVEMENT MAINTENANCE COSTS

	$Y=X_i$	$Y=\ln X_i$	$\ln Y=X_i$	$\ln Y=\ln X_i$
BO	4.61 (3.56)*	13.9461 (2.19)*	1.4523 (7.30)*	1.8007 (2.64)*
TC	-.0062 (-1.27)	-1.0052 (-.92)	-.0004 (-.88)	-.0767 (-.66)
TS	.2719 (4.86)*	1.8370 (3.44)*	.0262 (4.37)*	.1790 (3.14)
PS	.3197 (.20)	-.3822 (-.35)	-.0193 (-.16)	-.0857 (-.74)
AG	.0389 (2.18)*	.6255 (1.29)	.0041 (2.17)*	.0757 (1.46)
DST1	-1.2149 (-.89)	-1.3604 (-.83)	.0070 (.04)	.0051 (.0005)
DST2	.0279 (.01)	-.7834 (-.49)	-.0148 (-.08)	-.1014 (-.59)
DST3	2.2674 (1.35)	2.3453 (1.36)	.04508 (2.50)*	.4538 (2.47)*
DST4	.3704 (.28)	.4807 (.36)	.2618 (1.89)	.2723 (1.93)
F Ratio	4.31*	2.63*	4.35*	2.95*
MSE	.2745	.3257	.0257	.0306

## RIGID PAVEMENT PSR

	$Y=X_i$	$Y=\ln X_i$	$\ln Y=X_i$	$\ln Y=\ln X_i$
BO	3.2998 (9.39)*	2.7039 (3.23)*	1.1469 (12.20)*	.9707 (4.36)*
TC	.0002 (1.04)	-.9049 (-1.13)	.00005 (1.02)	-.0267 (-1.18)
TS	-.9148 (-3.50)*	.0016 (.02)	-.0043 (-3.76)*	-.0017 (-.10)
PT	.0074 (2.24)*	.3104 (1.86)	.0023 (2.62)*	.0944 (2.10)*
PS	.4539 (3.48)*	.7608 (5.62)*	.1367 (3.92)*	.2227 (6.10)*
MC	-.0180 (-2.50)*	-.0843 (-1.79)	-.0042 (-2.12)*	-.0195 (-1.53)
DST1	-.0411 (-.31)	-.0905 (-.68)	-.0066 (-.18)	-.0230 (-.64)
DST2	.2479 (.42)	-.0342 (-.29)	.0159 (.53)	-.0079 (-.25)
DST3	-.1454 (-1.47)	-.1463 (-1.39)	-.0359 (-1.35)	-.0366 (-1.29)
DST4	.2657 (2.21)*	.2746 (2.35)*	.032 (2.04)*	.0661 (2.10)*
F Ratio	15.34*	11.10*	16.63	11.72*
MSE	.1233	.1419	.0088	.0103

## RIGID-PAVEMENT MAINTENANCE COSTS

	$Y=X_i$	$Y=\ln X_i$	$\ln Y=X_i$	$\ln Y=\ln X_i$
BO	12.9091 (3.29)*	3.3843 (.35)	2.0890 (3.08)*	1.3678 (.87)
TC	.0053 (1.87)	2.7313 (2.83)*	.0006 (1.26)	.3257 (2.04)*
TS	.1216 (2.64)*	1.9777 (3.09)	.0362 (4.56)*	.5291 (5.01)*
PT	-.0545 (-1.44)	-.4133 (-1.32)	-.0069 (-1.07)	-.5268 (-1.75)
PS	-5.3854 (-3.83)*	-5.5198 (-3.79)*	-.6989 (-2.88)	-.8355 (3.47)
AG	.0170 (1.91)	-.0127 (.02)	.0029 (1.94)	.0843 (.93)
DST1	-2.933 (-1.99)*	-.4123 (-1.75)	-.4953 (-1.95)	-.3983 (-1.75)
DST2	-2.6147 (-2.12)	-2.5240 (-2.16)*	-.6469 (-3.04)*	-.5804 (3.00)*
DST3	-3.9286 (3.71)*	-4.1605 (-4.01)*	-.7015 (-3.84)*	-.7044 (-4.10)*
DST4	-1.1153 (-1.86)	-1.5319 (-1.26)	.0999 (.45)	.0485 (.24)
F Ratio	10.82*	10.58*	14.03*	16.45*
MSE	15.2559	15.3897	.4538	.4209